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Spins of Excited States of Some Odd A Nuclei According to the Collective Model*

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Abstract:

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capitol

The procedures used in recent papers to estimate the spins of the excited states of Np^{237} and Np^{239} and the rotational energy $\hbar^2/2J$ have been applied to levels of other isotopes as observed in α -decay. The levels and spins of Ac^{227} are as proposed by Moore.

The results which are consistent with the predictions follow:

Isotope	Level energy in kev and (spin)	$\hbar^2/2J$ (kev)	use German capitol
Po^{215}	0 (5/2) 270 (7/2) 622 (9/2)	38.7	
Ac^{227}	0 (3/2) 38 (7/2) 97 (11/2)	3.1	
	323 (7/2) 387 (11/2)	2.6	
Th^{229}	0 (5/2) 42 (7/2) 96 (9/2)	6.0	
Pu^{239}	277 (3/2) 321 (5/2) 382 (7/2)	8.8	

Em^{219} , Ra^{223} , U^{235} and Am^{241} are also considered.

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The energy level spacing of some heavy isotopes of odd A have been examined from the point of view of the collective model of the nucleus¹ to obtain predictions about the level spins. Rasmussen² has pointed out the excellent fit of some excited states of Np²³⁷ to the spacing predicted by equation VI.4 of Bohr and Mottelson¹:

$$E_I = (\hbar^2/2J) [(I + 1)(I) - I_0(I_0 + 1)]$$

The rotational energy ($\hbar^2/2J$, called herein Er) was found to be 6.3 kev, and the spins 5/2, 7/2, 9/2. Asaro and Perlman³ recently revised the level scheme of this isotope, eliminating the former ground state, and assigning the former 11 kev level as the ground state. Their spin assignments agreed with Rasmussen, but they assigned even parity to these states, the opposite to that of the ground state. They pointed out the similarity of the Np²³⁹ level structure, for which they found a value of Er equal to 5.6 kev.

Some of the isotopes which we have examined follow the Bohr-Mottelson theory with little deviation and yield consistent results. These are Po²¹⁵, Th²²⁹, Pu²³⁹, and Am²⁴¹. The isotope U²³⁵ agrees with the theory if there are some undiscovered levels so that the spins of the levels are not assumed to be an I, I + 1, I + 2, ... progression. Ra²²³ and Em²¹⁹ agree fairly well with the theory but are not as convincing as the others.

The isotope Ac²²⁷ is also exceptional in the level progression as well as in the value of Er obtained from it. These exceptions will be discussed more fully later.

Th²²⁹ is the daughter of U²³³. Asaro⁴ has given a decay scheme of U²³³ as in slide 1. Solution of the simultaneous equations gives a value for I₀ of $2.45 \approx 5/2$ with Er equal to 6.1 kev. If 5/2 is

assumed as the correct value, the two values of E_r obtained are both 6.0 kev. The spin value of $5/2$ is to be compared with the measured value for U^{235} of $5/2$. If U^{233} also has $5/2$ spin and the same parity as the ground state as Th^{229} then the most abundant α -transition has L_α (angular momentum) 0, the second most abundant probably 2, and the third most abundant probably 4, for reason of conservation of parity.

The ratios of these α groups are roughly comparable to those of neighboring even-even isotopes, which are believed to have angular momentum of 0, 2, and 4.

slide 2

The spin of the ground state of Pu^{239} has recently been measured as $1/2$ by Van den Berg⁵ et. al. The α decay of the parent Cm^{243} and the β decay of Np^{239} lead to the level scheme of Pu^{239} as proposed by Asaro⁴. Considering the levels at 277, 321 and 382 kev, the simultaneous equations give values for I_0 of 1.58 and E_r of 8.5 kev. If $I_0 = 3/2$ is used in the equations then E_r is 8.8 kev. According to Asaro⁴ the character of the 277 kev transition is probably M-2. I_0 equal $3/2$ would seem to be incompatible with the ground state spin and nature of the transition, although it would be an allowed transition, but not the lowest allowed.

slide 3

The α -decay of Pu^{239} to U^{235} is similar to that of Am^{241} , with respect to the fact that the most abundant α groups do not go to the ground state. The ground state spin of U^{235} is $5/2$ and Pu^{239} is $1/2$. This is the decay scheme proposed by Asaro⁴. At first we will consider the level '0' and '0.052'. Considering the conversion electron data and the conversion coefficient of $\approx 1.4 \times 10^5$

the 52 kev γ is probably an E-2 transition. Thus these two levels probably have the same parity. Assuming that level 0.051 has $I_0 + 2$ spin, the equations give a value of Er of 5.8 kev, for $I_0 = 1/2$. On the other hand, if the 51 kev level has $I_0 + 1$ spin, the value for Er is 12.8 kev. This value is much larger than expected, and may be excluded on that basis. Spin values of $3/2$ and larger for a progression of $I_0, I_0 + 2$, may be excluded as being too small. However, values of $3/2, 5/2$, and $7/2$ for I_0 , with the progression $I_0, I_0 + 1$, may not be excluded.

Since we would prefer La to ^{be} ^{140}La or ^{141}La for the most abundant α -group analogously to the Am^{241} decay we may tentatively exclude $I_0 = 5/2$ and $7/2$ on that account. Thus we have the two possibilities:

$$(1) I_0 = 1/2, I_{51} = 5/2 \quad \text{Er} = 5.7 \text{ kev.}$$

$$(2) I_0 = 3/2, I_{51} = 5/2 \quad \text{Er} = 10.2 \text{ kev.}$$

Now if the 13 kev level had a spin of $I_0 + 1$, with I_0 equal $1/2$, the equation gives Er as 3.25 which is in rather poor agreement with previous the value of 5.7. There may, however, be some experimental error in the energy of the α -particle going to the 13 kev level, and thus the true value might give better agreement.

slide 4

This is the level scheme of Am^{241} based on the α -energies as obtained by Ghiorso⁶ and collaborators. The solution for the simultaneous equations give $I_0 = 1.28$, and $\text{Er} = 39$. If one uses $I_0 = 3/2$ then Er is 38.5 kev. This result can be considered only tentative, for the decay scheme is not well known in this case.

The decay scheme of Pa^{231} , and the level spins of Ac^{227} are shown in slide 5. This scheme was proposed by Moore⁷ on the basis of angular correlation and conversion coefficients. The ground state

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spin has been reported to be $3/2$ for both isotopes. Taking levels 0, 2, 3 as rotational levels in the sequence $3/2, 7/2, 11/2$, values for Er of 3.18 and 3.04 kev are found. If these levels were assumed $3/2, 5/2, 7/2$, the values for Er would be 7.5 and 12.4, which clearly, are not as consistent as the previous values. The value of 3.1 kev for the rotational energy is anomalously low compared with the value of 9.7 and 11.1 for Th^{228} and Ra^{226} , but is about the value predicted by Bohr and Mottelson for a rigid rotator. Furthermore, the values for the rotational energy found for the other odd A isotopes in this region, are all considerably below that found from the even-even nuclei, although not as much as this.

If we consider the levels 4, 5, and 6 as being rotational levels of the opposite parity as those above, with spins either $3/2, 7/2, 11/2$; $3/2, 7/2, 9/2$; or $5/2, 7/2, 9/2$, we are unable to find consistent values for Er. If we take only levels 5, and 6 for rotational levels, we find Er is 5.5 kev for $7/2, 9/2$ spin and 2.6 kev for $7/2, 11/2$ spin. Since the $7/2, 11/2$ spin arrangement is considered the most probable relationship from the decay scheme, and the rotational energy 2.6 kev agrees with that obtained from the lower levels, we think that the $11/2$ spin state is probably the rotational state corresponding to the $7/2$ spin state.

slide 6

This fig. shows the decay of Em^{219} as given in the Table of Isotopes.⁸ The solution of the simultaneous equation gives $I_0 = 2.3$ and $\text{Er} = 31$. If $I_0 = 5/2$ is used, the average value of Er becomes 38.7. Note, that once again in this decay, we have three α -groups of the same parity in roughly the same abundance as Am^{241} , Am^{243} , U^{233} ,

and similarly to Cm^{243} and Pu^{239} , there is an additional group of moderate abundance whose parity is unknown. The parity for this group is probably opposite to that of the main groups of α decay.

Ra^{223} is the daughter of the α -emitter Th^{227} . A recent paper of Rosenblum⁹ and collaborators has shown that the low levels of Ra^{223} are arranged as in slide 7. They have assigned the multipole orders to the transitions as indicated. These transitions indicate that the lowest three levels have the same parity. If the spin of the ground state and the 30 and 60 kev states are assumed to be in progression $I, I + 1, I + 2$, the simultaneous equations for I_0 and Er do not give a unique solution except for $Er = 0$ and $I_0 = \infty$. If the value of I_0 is assumed to be $3/2$, however, the two equations yield the consistent values of 6 and 5 kev for Er . Higher values of I_0 give lower values of Er . Consequently, the higher values of I_0 are believed to be less probable. If the correction is used for spin $1/2$ as given by Bohr and Mottelson¹, and the equations solved with $I_0 = 1/2$, the values obtained for Er are 7.5 and 6.7 kev, also quite consistent. The choice between these two spins is therefore not clear cut. Spin $1/2$ would be slightly favored because the rotational energy obtained from it would be closer to the 14 kev value of Ra^{224} .

slide 8

This shows the level scheme of Am^{241} deduced from the α -particle groups found by Asaro and Perlman¹⁰. Taking the levels at 31, 113 and 317 kev, I_0 is found by the simultaneous equations to be $8/10$ and Er is 31 kev. However, using the equations corrected for spin.

$1/2 - .6$ is obtained for I_0 which is not such a good answer.

Using the equations corrected for $1/2$, a value of about 30 kev is found for Er. Considering the lack of knowledge of the level scheme of this isotope, the fit is fairly good, but the result is, of course, only tentative.

Note that an assumption that all the α -particle groups have different L values implies that the spin of Ra^{223} would have to be $> 1/2$. If it were not, the only α values of even parity to the $3/2$ and $5/2$ state of Er^{219} would be $L = 2$. If odd parity, then the groups going to the $1/2$ and the $3/2$ state would both be 1.

Work is in progress to determine the level widths of α -groups going to the levels we have discussed herein. The equations recently suggested by R. G. Thomas¹¹ will be used. The various possibilities of the spin and $L\alpha$ will be studied.

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α
ABUNDANCE
(%)

13
21
5
19

$7/2$
 $5/2$
 $3/2$
6
5 KEV

$5/2$
 $3/2$
 $1/2$
6.7
7.5

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12

4-12-19

$I_0 = 1.58$; $\frac{3}{2}$
 $E_r = 8.5$; 8.8 KEV

Pu²³⁹

Cm²⁴³

14

15

$I_0 = 2.45; 5/2$

$E_r = 6.1; 6.1 \text{ KEV}$

x-19-15

			ENERGY OF LEVELS				LEVEL			MULTIPOLE ORDER AND PARITY OF TRANSITION							
			LEVEL NUMBER	FROM CONVERSION ELECTRON DATA	FROM α DATA	FROM γ DATA	α ABUNDANCE	SPIN	PARITY	α ANGULAR MOMENTUM	SPIN OF LEVEL	TRANSITION TO INDICATED LEVELS					
			6	383	391		1-3%	11/2	+	5	7/2+	0	1	2	3	4	5
			5	331	329	318	11%	7/2	+	3	9/2+	M2	M1				E1
											11/2+	E3	E2				M1
											M4	M3					E2
											7/2+	M2	M1	E1	M2	M1	
											5/2+	E1	M1	E1			
											5/2-	M1	E1	M1			
											7/2-	E2	E1	M1			
											3/2+	E1	M1	E2			
											3/2-	M1	E1	M2			
			4	198	208		3%	5/2	+	1	1/2	ISOTROPIC CORRELATION					
											5/2+	E1	M1	E1	E3		
											5/2-	M1	E1	M1	M3		
											3/2+	E1	M1	M2	M4		
											3/2-	M1	E1	E2	E4		
											7/2+	M2	M1	E1	M2		
			3	97	107	95	25%	11/2	-	4	7/2-	E2	E1	M1	E2		
											11/2-	E4	E3	E2			
											9/2-	M3	M2	M1			
											1/2+	M4	M3	M2			
			2	38	40		47%	7/2	-	2	9/2+	E3	E2	E1			
											7/2-	E2	E1				
			1			27	NONE	5/2	+		7/2+	M2	M1				
											5/2+	E1					
			0				11%	3/2	-	0							

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ZnS(Ag) Phosphor Mixtures For Neutron Detection

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47119

University of California, Los Alamos Scientific Laboratory

In a search for a fast neutron detector with minimum gamma response, the scintillation characteristics of ZnS(Ag) were re-examined. The principal decay constant of ZnS(Ag) was measured as $\sim 0.04 \mu \text{ sec}$ with a fast scope (Tektronix 517) and short anode time constant ($\sim 5 \times 10^{-9}$). τ was found to be independent of the mode of excitation (alphas or electrons from gammas) and, as expected, measured values of τ increased with slower electronics. ZnS(Ag) thus appeared sufficiently promising to warrant a brief survey of various mixtures of this phosphor with boron, lithium, and fissionable compounds for neutron detection. Various atomic ratios and thicknesses were tested for each mixture. 100 mg/cm^2 of a mixture of finely ground boric acid powder and ZnS(Ag) powder (atomic ratio 1B/1.5 Zn) yielded the highest neutron counting efficiency, $\epsilon_n \sim 1\%$, with a ratio of neutron-to-gamma counting efficiency $> 10^5$. Increased ϵ_n is obtained at the expense of $\epsilon_n/\epsilon_\gamma$ ratio. Various mixtures of boric acid and ZnS(Ag) were compression-molded into thin discs using a hydrogenless binding agent. Optimum counting efficiencies for these discs fell considerably below that of the powder mixtures.

*On leave from the College of Wooster, Wooster, Ohio.

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